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Analysis of drivers and policy implications of carbon dioxide emissions of industrial energy consumption in an underdeveloped city: The case of Nanchang, China

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ABSTRACT

Currently, little attention has been paid to reducing the carbon dioxide (CO_2) emissions of underdeveloped cities to combat climate change, especially in central China. Taking Nanchang as a case study, we computed this city's CO_2 emissions (CE) from industrial energy consumption and analyzed the corresponding drivers using the logarithmic mean Divisia index (LMDI). The results showed that economic output was mainly responsible for the CE growth followed by population with average annual contribution rates of 26.00% and 2.27%, respectively. In contrast, energy intensity presented the most clear mitigation effect followed by industrial structure, the mitigating effect of energy mix was the least impactful, and the average annual contributions were −10.71%, −4.20% and −1.40%, respectively. Moreover, the CE from "fuel combustion" exhibited a clear fluctuation due to the economic crisis, but the CE of "electricity and heat" exhibited only a slight variation because the consumption of the former could be easily reduced but reducing consumption of the latter is difficult in everyday life. In addition, in the traditional modes of economic development, I19 (smelting and processing of ferrous metals), I30 (production and supply of electric power and heat power) and I15 (manufacture of raw chemical materials and chemical products), were always among the top 3 contributing sub-sectors. However, in the 'new normal', I26 (manufacture of communication equipment, computers and other electronic equipment) and I2 (processing of food from agricultural products) were first among the top 3 sub-sectors. Thus, these sub-sectors should be given priority when designing related reduction policies. Specific countermeasures or suggestions for reducing Nanchang's CE were recommended.

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1. Introduction

Climate change is one of the most dangerous and complex issues human beings have ever encountered (Lin et al., 2013, 2017; Lin and Ahmad, 2015). Cities are the hubs of socio-economic activity (Yu et al., 2015). Statistically, there are more than 3.6 billion people living in cities of the total 7.1 billion alive in the world (Gouldson et al., 2015). In addition, it is predicted that the urban population will surpass 6.7 billion in 2050 (UNDESA, 2014). With this accelerating urbanization, more and more fuel (or energy) will be used in the cities. Therefore, the carbon dioxide (CO_2) will also be increasingly emitted into the atmosphere, which, in turn, results in an acceleration of global warming (Wang et al., 2015). If we do not

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take any effective actions, the world's average temperature will increase by approximately 5.8 °C during the next 100 years. This result poses a huge threat to global sustainable development (Ren et al., 2015). In addition, the Intergovernmental Panel on Climate Change (IPCC) has estimated the consumed fuels and other activities within cities account for approximately 44% of global CO_2 emission (CE). When considering the final consumption of electricity, the proportion of emissions that can be attributed to cities may reach approximately 71–76% (IPCC, 2014). Other studies have also shown that when considering the wider consumption-based impacts, the proportion of CE attributable to cities may be much higher (Satterthwaite, 2008; Hoornweg et al., 2011; Feng et al., 2014). Thus, it can be seen that it is necessary and urgent for us to study the CE of cities and related adaptive measures more thoroughly to better combat climate change (Xi et al., 2011).

China, the world's largest developing country, has contributed approximately 80% of the world's rise in CE since 2008 (Liu et al., 2013). In 2009, China established a series of targets to reduce CE, e.g., decreasing carbon intensity to 17% below 2010 levels by the year 2015 and to 40–45% below 2005 levels by the year 2020 (Cong and Wei, 2010; Liu et al., 2015a, b). In 2012, China discharged 7.9 Gt CO_2, which was the greatest share and approximately a quarter of worldwide emissions at that time (IEA, 2013; Yang et al., 2015). China has already become one of the top energy consumers as well as the top CO_2 emitter in the world (Chen and Lin, 2015; Mi et al., 2016, 2017a). Thus, it can be concluded that we should give sufficient attention to this country to reduce related CE, especially in cities. In reality, people have begun some studies on the CE of this country and urban areas in China. For example, when analyzing the growth of global CE, Jiang and Guan (2016) found that among all countries, China accounted for a high contribution and accounted for a growth in coal use-related CE of up to 2.79 Gt from 1995 to 2009. Reliable energy statistics for estimating China's CE were investigated from the perspectives of transparency, accuracy and uncertainty (Guan et al., 2012, 2014; Liu et al., 2015a, b), and the potential peak of China's CE prior to 2030 was assessed from the perspective of socio-economic impact (Mi et al., 2017a, b). In addition, the factors influencing the CEs of China's energy consumption were also analyzed (Xu et al., 2016a, b).

The studies that have been conducted on the status, drivers and development strategies of China's CE can be categorized into industrial and regional perspectives (Liu et al., 2012a, b; Li et al., 2015). From the industrial sector's perspective, Lindner et al. (2013) developed a bottom-up model to calculate the direct CE embodied in China's electricity sector. Moreover, Yan and Fang (2015) researched the historical trajectory and features of CE in China's manufacturing sector and investigated its influencing factors. Similarly, Shan et al. (2016a, b) studied the CE of China's lime production from 2001 to 2012. In addition, Zhao et al. (2017) analyzed the decoupling relationship of China's economic growth from its CE in five major economic sectors such as agricultural sector, industrial sector, etc. For the second perspective, the region may be one or several provinces, a coastal region or even an urban area. Taking the Liaoning Province as an example, Geng et al. (2013) explored the factors driving energy-related CE in Chinese provinces. Then, Shan et al. (2016a, b) employed an “apparent energy consumption” approach and updated emissions factors to recalculate Chinese provincial CEs during 2000–2012 to reduce the uncertainty in Chinese CE estimates. Moreover, Xu et al. (2016a, b, 2017) comparatively analyzed the provincial contributions to China's CE and national carbon intensity by using the logarithmic mean Divisia index (LMDI) and structural decomposition analysis (SDA) methods based on the input-output (IO) table, respectively. Gao et al. (2016) examined the drivers of energy-related CE in eastern and southern coastal China and expanded the knowledge on the commonality and variation in these coastal regions. Similarly, Zhou et al. (2017) comparatively studied the decoupling relationship between regional economic development and industrial energy-related CE in southern and northern coastal regions in China. Taking one coastal region as a case, Song et al. (2015) analyzed the factors driving energy consumption-related CE in the Yangtze River Delta of China.

At the city scale, Lee and van de Meene (2013) analyzed the relationships between CE and other environmental indicators and compared the differences among cities in China, such as Shanghai, and other Asian cities, such as Bangkok. However, some scholars did not take specific cities as examples but rather divided China into urban and rural regions for analyzing CE-related problems. For example, Liu et al. (2011) categorized China's household CE into direct and indirect sources and estimated CE for urban and rural regions. Similarly, Fan et al. (2012) and Han et al. (2015) studied the structural changes and drivers of urban household CE in China. Wang and Yang (2014) analyzed the drivers of indirect CE for China's household consumption from urban and rural regions. In addition, Zhang et al. (2017) studied the critical factors for low-carbon buildings in China's urban areas for the reduction of the CE of the building sector. Nevertheless, more scientists have taken specific or typical cities as cases to conduct related studies of urban carbon reduction. Some major findings regarding the specific studied cities, contents and methods are listed in Table 1. For example, taking Shenyang city as a case, Xi et al. (2011) constructed a CE inventory and completed the calculation using the methods described by the IPCC guidelines, and Sun et al. (2016) discerned the drivers of carbon consumption using LMDI and other methods. The explanations for other urban studies in Table 1 can be similarly illustrated but are not presented to save space.

From Table 1, we can conclude that to date, researchers have often focused on studying developed cities along the east coast, such as Shanghai and Dalian, or on cities with extremely harsh environments in the west, such as Guangyuan, an earthquake-stricken city. However, underdeveloped regions, especially those in central China, such as Jiangxi Province, have not received enough attention, and few findings can be found in the existing literature around the world. Therefore, taking Nanchang, the capital city of Jiangxi Province, as a case, we attempt to study the industrial CE of this city in this paper, which has some innovative significance. To a certain extent, this study compensates for a lack of studies on urban CE in underdeveloped areas, especially in areas in central China, such as the Poyang Lake Ecological Economic Zone (PLEEZ).

Generally, there were two commonly used decomposition methods (Xiao et al., 2016; Liu et al., 2012b), namely, SDA and index decomposition analysis (IDA). SDA often requires the economic data to be in the form of an IO table, while IDA only requires aggregate data for each industrial category (Cansino et al., 2016; Yang et al., 2016). Moreover, SDA can only analyze the change between a limited number of years, while IDA can usually analyze changes between any years (Cellura et al., 2012). In addition, there were still many optional indexes in the IDA models. These indexes were, for instance, Laspeyre's index (Lu et al., 2014), Paasche index (Liu et al., 2016), Arithmetic Mean Divisia index (Hatzigeorgiou et al., 2008) and LMDI (Ang, 2005; Lee and Oh, 2006; Wood and Lenzen, 2006). Among these indexes, LMDI has become the most popular because of its incomparable advantages (Chen, 2011; Ren et al., 2012; Zhang et al., 2013). It was concluded that the LMDI has some outstanding properties in terms of theoretical foundation (i.e., no unexplained residuals), adaptability, ease of use, and the interpretation of results (Ang, 2004; Ang and Liu, 2007; Ang et al., 2003). So, as shown in Table 1, the SDA model and LMDI methods are both used for discerning the drivers of typical urban CE in China.

However, considering the data unavailability in the IO table for

Table 1
The specific cities, contents and methods from major studies on urban CE in China.

Cities	Contents and Methods	Articles
Beijing	- Using IO analysis to calculate the CE of fossil fuel use and other industries and carbon consumption, etc.; -Adopting SDA method to discern the drivers of CE.	Wang et al. (2013); Zhang et al. (2015); Shao et al. (2016a, b); Xia et al. (2017).
Shanghai, etc.	- Calculating and analyzing the consumption-based CE of thirteen typical cities by IO model.	Mi et al. (2016).
Shenyang	- Constructing the CE inventory and completing the calculation by IPCC guidelines. - Discerning the drivers of carbon consumption by LMDI and other methods.	Xi et al. (2011); Sun et al. (2016)
Ningbo, etc.	- Comparing the pathways and patterns of low-carbon transformation among several cities.	Higgins (2013); Mat et al. (2016)
Dalian	- Exploring the optimized scheme of industrial structure adjustment by LMDI.	Chen et al. (2016)
Xiamen	- Analyzing household low-carbon behaviors for reducing the direct CE.	Ye et al. (2017)
Urumqi	- Discussing the implications of the Five-Year Plan on the CE reduction by LEAP and scenario analysis.	Zhou et al. (2016)
Guangyuan	- Urban carbon cycle accounting for analyzing the impacts of earthquake and reconstruction by IPCC guidelines.	Hao et al. (2015)

Notes: LEAP means the "Long Range Energy Alternatives Planning System" developed by the Stockholm Environment Institute (SEI) in the 1980s.

Nanchang, we can only adopt the LMDI method to analyze the potential drivers of this city's industrial CE. The rest of the text is arranged as follows. The descriptions of data and urban status are in section 2. The detailed methodology is in section 3. The analysis of results and the related discussion are presented in section 4. The conclusions and certain countermeasures and suggestions for an industrial low-carbon future and the development progress of Nanchang are presented in section 5.

2. Data description

Nanchang is located between 28° 09′ - 29° 11′ N and 115° 27′ - 116° 35′ E with an administrative area of 7402 km^2. In China's first "Low-Carbon Pilot Cities" national project in 2010, 8 cities and 5 provinces were assigned the task of pursuing a low-carbon economics transformation. Nanchang was one such city and made the commitment to take efficient action to decrease its energy intensity and CE. On the other hand, in recent years, this city has been drawing more and more attention from the outside world because of certain economic policies the city has passed. For example, Nanchang was approved for establishing a comprehensive free trade area in 2016. The goal of this policy was to foster more opportunities to transform the development of the city and to update the industrial structure.

The related economic and energy data are mainly derived from the Nanchang Statistical Yearbook (NSY). There are two kinds of statistical measures of industrial energy consumption. One measure is based on fuel types, and another is derived from the different sub-sectors. The total energy consumption of the former is consistent with that of the latter. The former's data can be used to calculate the total CE of industrial energy consumption, and that of the latter can be used to decompose the contributions of sub-sectors. However, it is notable that the industrial statistics on particular sub-sectors before 1999 had not been found from the NSY, related bulletins or the official website of statistics bureau. Moreover, the NSY of the recent year (2017) has not been published to date. However, based on the LMDI model, we cannot conduct the decomposition analysis of industrial sub-sectors without these particular data in this paper. Therefore, we can only use the related yearbooks' data for 1999–2016. The corresponding study period was from 1998 to 2015.

In addition, in order to eliminate the influence of price changes, we deflated the raw data at the current prices to constant 2010 prices using the corresponding price indices. Similarly, to obtain more accurate results, we considered all nine fossil fuels reported in the statistical yearbooks, namely, raw coal, cleaned coal, other cleaned coal, coke, crude oil, gasoline, kerosene, diesel, and fuel oil. The amount and share of weapons and ammunition manufacturing (WAM) in Nanchang were marginal, and were close to 0 in most years, so, the WAM industry was excluded. Similarly, some other industries were also excluded. Consequently, in the end, 32 industrial sub-sectors were investigated and are listed in Table A1.

Nevertheless, the specific energy consumption data on electricity and heat exhibited very different features from the other fuel use data in the Nanchang's NSY. Thus, for the analysis, we divided them into two categories. The other fuel uses, excluding electricity and heat, represented the first category, "fuel combustion." The energy consumption of electricity and heat was the second energy category and was given the title "electricity and heat." In addition, to make the related analysis progress and results more clear, we divided the changes of the total CE and the subsequent indicators into four stages. The four stages were 1998–2000, 2001–2005, 2006–2010 and 2011–2015, and each was separated by the three "white points" (Fig. 1b). Among the periods, the last was coincided with the 12th "Five-Year Plan" proposed by the Chinese government and is viewed as the "new normal" of China's economic development (Mi et al., 2017a).

3. Methodology

3.1. CE of industrial energy consumption

Total CE of industrial energy consumption included all the emissions arising from different kinds of industrial sub-sectors, e.g., the paper-making industry, the processing of food from agricultural products, and others. We can calculate the CEs for these industries using the following equation (Kennedy et al., 2010; Wang et al., 2012):

$$C = \sum_i \sum_j C_{ij} = \sum_i \sum_j E_{ij} \cdot f_j \quad (1)$$

where i denotes the different sub-sectors of industrial departments (e.g., leather and paper making); j denotes the energy type (e.g., washed coal, liquefied gas and coke oven gas), and the other specific variables are defined in Table 2. Based on the IPCC (2006, 2014) and other studies (Kennedy et al., 2009, 2014), the CE coefficients for different types of energy are listed in Table A2. The CE coefficient of heat can be calculated as 0.11 t-CO_2/GJ by the equivalent calorific value (Bi et al., 2011). In addition, China's CE coefficients of electricity are used for CE computation due to the data lack in Nanchang city. These coefficients can be acquired directly from the International Energy Agency (IEA) statistics 2011–2015 and are listed in Table A3.

3.2. Decomposition model of drivers

According to the LMDI model, the total CE can be expressed as

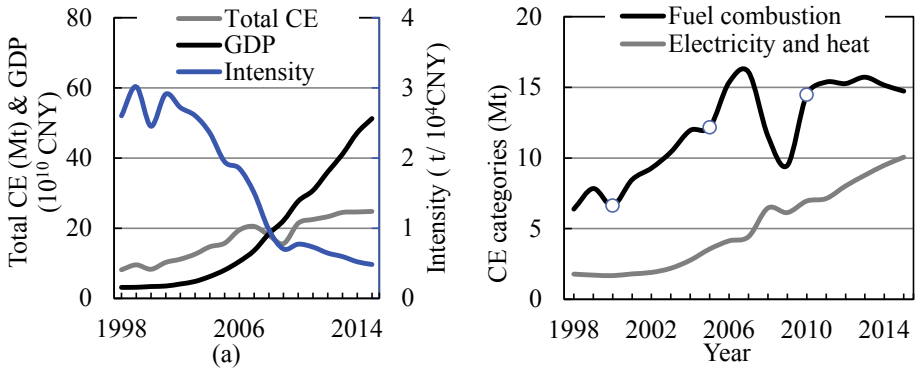

Fig. 1. (a) The total CE of industrial energy consumption, industrial GDP, CE intensity and (b) the CEs from two different categories.

Table 2
Definition of variables.

Variable	Definition
C	Total CE of industrial energy use
C_{ij}	CE from consumption of energy j by sub-sector i
E_{ij}	Consumption of energy j by sub-sector i
f_j	CE's coefficient of energy j
P	Population of Nanchang city
I	Gross domestic product (GDP) of all sub-sectors
I_i	GDP of sub-sector i
E_i	Energy consumption of sub-sector i
IE_i	Energy consumption per unit of GDP in sub-sector i
IS_i	Share of sub-sector i in total GDP
ES_{ij}	Share of energy j in sub-sector i
IP	GDP per unit of population

the following extended identity:

$$C = \sum_i\sum_j C_{ij} = \sum_i\sum_j \frac{C_{ij}}{E_{ij}}\cdot\frac{E_{ij}}{E_i}\cdot\frac{E_i}{I_i}\cdot\frac{I_i}{I}\cdot\frac{I}{P}\cdot P = \sum_i\sum_j f_j\cdot ES_{ij}\cdot IE_i\cdot IS_i\cdot IP\cdot P \quad (2)$$

where the variables are also defined in Table 2.

Thus, based on the additive LMDI method, the total CE can be decomposed into the following effects.

Carbon emission coefficient effect:

$$\Delta C_f = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{f_{ij,T}}{f_{ij,0}} \quad (3)$$

Energy structure effect:

$$\Delta C_{ES} = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{ES_{ij,T}}{ES_{ij,0}} \quad (4)$$

Energy intensity effect:

$$\Delta C_{IE} = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{IE_{ij,T}}{IE_{ij,0}} \quad (5)$$

Industrial structure effect:

$$\Delta C_{IS} = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{IS_{ij,T}}{IS_{ij,0}} \quad (6)$$

Economic output effect:

$$\Delta C_{IP} = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{IP_{ij,T}}{IP_{ij,0}} \quad (7)$$

Population effect:

$$\Delta C_P = \sum_i\sum_j \frac{C_{ij,T} - C_{ij,0}}{lnC_{ij,T} - lnC_{ij,0}}\cdot ln\frac{P_{ij,T}}{P_{ij,0}} \quad (8)$$

where the subscripts *0* and *T* denote the baseline period and target period, respectively. Thus, the change in total CE (ΔC_{TOT}) between the base period (C_0) and target period (C_T) can be written as:

$$\Delta C_{TOT} = C_T - C_0 = \Delta C_f + \Delta C_{ES} + \Delta C_{IE} + \Delta C_{IS} + \Delta C_{IP} + \Delta C_P \quad (9)$$

According to Shao et al. (2016a, b) and Kamaruddin et al. (2012), the corresponding multiplicative formation of LMDI decomposition can be written as the follows:

$$\Psi C_{TOT} = C_T/C_0 = \Psi C_f\cdot\Psi C_{ES}\cdot\Psi C_{IE}\cdot\Psi C_{IS}\cdot\Psi C_{IP}\cdot\Psi C_P \quad (10)$$

where $\Psi C_\zeta = \exp\left(\sum_j\sum_j \frac{(C_{ij,T}-C_{ij,0})/(\ln C_{ij,T}-\ln C_{ij,0})}{(C_T-C_0)/(\ln C_T-\ln C_0)}\cdot\ln\frac{\zeta_{ij,T}}{\zeta_{ij,0}}\right)$, and ζ denotes *f*, *ES*, *IE*, *IS*, *IP* and *P*. ΨC_{TOT} denotes the multiplicative formation of the total CE change from the base period (C_0) to the target period (C_T).

It should be noted that the CO_2 emission coefficients of various fuels are all assumed to be fixed when calculating Nanchang's CE. Therefore, in reality, the fuels have no contributions to changes in CE. In other words, here, the ΔC_f and ΨC_f in equations (9) and (10) should be 0 and 1, respectively. Thus, Nanchang's CE changes were decomposed into the following five effects: the population effect (ΔC_P and ΨC_P), economic output effect (ΔC_{IP} and ΨC_{IP}), industrial structure effect (ΔC_{IS} and ΨC_{IS}), energy intensity effect (ΔC_{IE} and ΨC_{IE}), and energy structure effect, which is also called the energy mix effect (ΔC_{ES} and ΨC_{ES}).

4. Results and discussion

4.1. The CE of industrial energy consumption

As shown in Fig. 1a, the industrial GDP of Nanchang was only 3.14×10^{10} Chinese Yuan (CNY) in 1998. It grew steadily to 51.26×10^{10} CNY in 2015 with the rapid development of industrialization and urbanization. The annual average amount of increase was 2.83×10^{10} CNY, and the corresponding growth rate was 17.85%. Similarly, the total CE of industrial energy consumption

increased from 8.17 million tons (Mt) in 1998 to 24.79 Mt in 2015, with an annual average increase amount of 0.98 Mt and a growth rate of 6.75%. Nevertheless, the total CE exhibited clear changes during 2006–2010 because of the global economic crisis that commenced in 2008, and the increases of CE and rates thereof were lower than those of GDP. Therefore, the CE intensity had a total decrease from 2.60 t/10^4 CNY in 1998 to 0.48 t/10^4 CNY in 2015 with the annual average change amount of −0.12 t/10^4 CNY and rate of −9.42% (Fig. 1a).

Like the total CE, the CE from "fuel combustion" was 6.38 Mt in 1998 and increased to 14.73 Mt in 2015, exhibiting similar variations due to the economic crisis during 2006–2010. However, the "fuel combustion" CE had clear variable changes during the period of 2011–2015 that were evidently different from the change in the CE of "electricity and heat" (Fig. 1b). The CE of "electricity and heat" was 1.78 Mt in 1998 and increased to 10.06 Mt in 2015. However, the CE of "electricity and heat" mostly continued to steadily increase during 2011–2015. In addition, the CE of "electricity and heat" had only a slight fluctuation during 2006–2010, which indicated that it was less affected by the effect of the economic crisis in 2008 than the CE of "fuel combustion."

The most important reason behind the change in the CE of "fuel combustion" is that the global economic crisis commenced in 2008. People could easily reduce all kinds of expenditures in everyday life when the crisis arrived. These saving behaviors could reduce all kinds of fuel usage and decrease the corresponding CEs. However, the use of "electricity and heat" could not fall because these consuming behaviors were dominated mainly by people's habits and customs. Changes to these living habits would need quite a long time to manifest. Thus, it was important and necessary to expand the related activities of communication and education about low-carbon living customs to help people achieve these changes to their customs, especially for saving electricity and heat.

4.2. Drivers of CE's changes at four stages

Based on the LMDI model mentioned above, the total CE change was decomposed into five factors (drivers), and these drivers' changes in four different stages were also analyzed to provide a deeper understanding of the potential mechanisms. Fig. 2 shows the multiplicative decomposition results, and the corresponding additive decomposition results are presented in Fig. 3. The detailed additive decomposition results for total CE and the five drivers are listed in Table A4. The contributions of various drivers to the total changes in CE are listed in Table 3. Here, "contributions" refers to the proportion of the change in total CE caused by each driver at time T (i.e., the additive decomposition result of each driver) compared to the total CE at time 0.

It can be easily seen that the CE of industrial energy consumption in Nanchang increased by 0.14 Mt with a growth rate of 1.72% in the first stage of 1998–2000 (Figs. 2a and 3a, Table 3), and then steadily increased by 7.42 Mt at a rate of 89.34% in the second stage of 2001–2005 (Figs. 2b and 3b; Table 3). In the third stage of 2006–2010, this CE increased again by 5.71 Mt at a rate of 36.28% (Figs. 2c and 3c; Table 3) and grew by 3.35 Mt at a rate of 15.60% in the fourth stage of 2011–2015 (Figs. 2d and 3d; Table 3). Overall, the total CE exhibited a sequentially increasing trend with a total growth rate of 203.42% (Table 3).

For 1998–2015, the contributions of drivers to CE growth in Nanchang, ranked from high to low, were the economic output effect (442.06%) and the population effect (38.60%), while the mitigating drivers were the energy mix effect (−23.8%), the industrial structure effect (−71.36%) and the energy intensity effect (−182.08%). The total promotion effect (480.66% = 442.06% + 38.60%) was more than the total mitigating effect

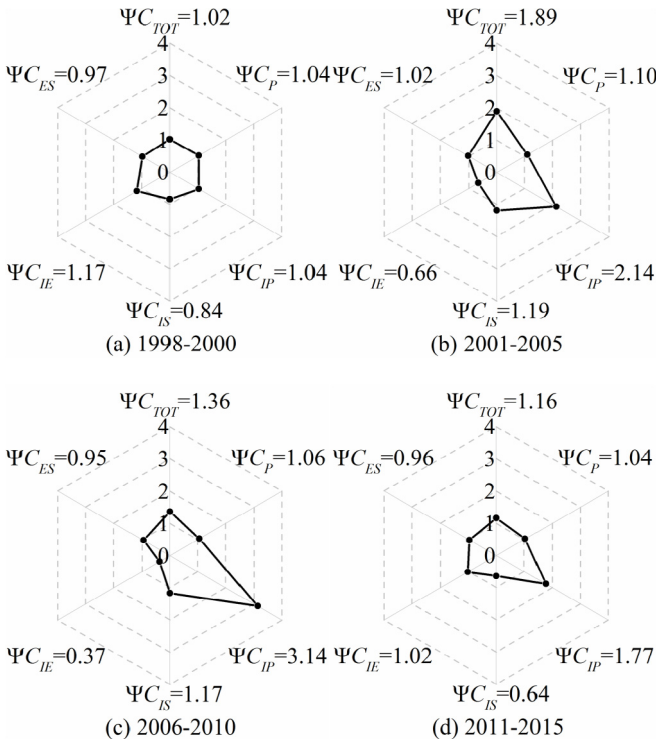

Fig. 2. Multiplicative decomposition results of the CE changes from industrial energy consumption in the four stages (ΨC_{TOT}, ΨC_P, ΨC_{IP}, ΨC_{IS}, ΨC_{IE} and ΨC_{ES} denote the total changes of the total CE and the effects of population, economic output, industrial structure, energy intensity and energy mix, respectively). (a) 1998–2000. (b) 2001–2005. (c) 2006–2010. (d) 2011–2015.

(−277.24% = −23.8% - 71.36% - 182.08%), which caused a 203.42% increase in the total CE in the studied period (Table 3).

To smooth the short-term fluctuations of various drivers, the cumulative decomposition results were converted from the multiplicative decomposition results in Table A5 and are listed in Table A6 and depicted in Fig. 4. The change of total CE and contributions of five decomposition drivers at various four stages are shown in Fig. 5. The average annual contribution rate of each driver and the change rate of the total CE at the four stages are listed in Table 4.

4.2.1. Economic output

It was apparent that only economic output always had a positive effect on CE growth, and economic output effect trended sharply upward during 1998–2015 (ΨC_{IP} in Fig. 4), which was consistent with the results in Fig. 5 and Table 4, e.g., it could also be easily seen that the dominant driver influencing the increase in the CE of industrial energy consumption in Nanchang was the increase in gross output (Fig. 5). Specifically, the additive decomposition effect of economic output on the CE was only 0.30 Mt in 1998–2000 (Fig. 3), indicating that economic output was a typical driver of CE growth during 1998–2000. However, in 2001–2005, 2006–2010 and 2011–2015, the decomposition effects increased greatly to 8.85 Mt, 21.08 Mt and 13.19 Mt (Fig. 3), respectively. In total, the effect of economic output made the greatest contribution to the total annual rate of the CE growth (26.00%) (Table 4), and for each of the four stages, the average annual contribution rates were 1.83%, 21.31%, 26.8% and 12.3%, respectively (Table 4). Therefore, simply stated, the growth in economic output growth was the most prominent determinant driving the increase in the total CE, although it was usual in stage 1.

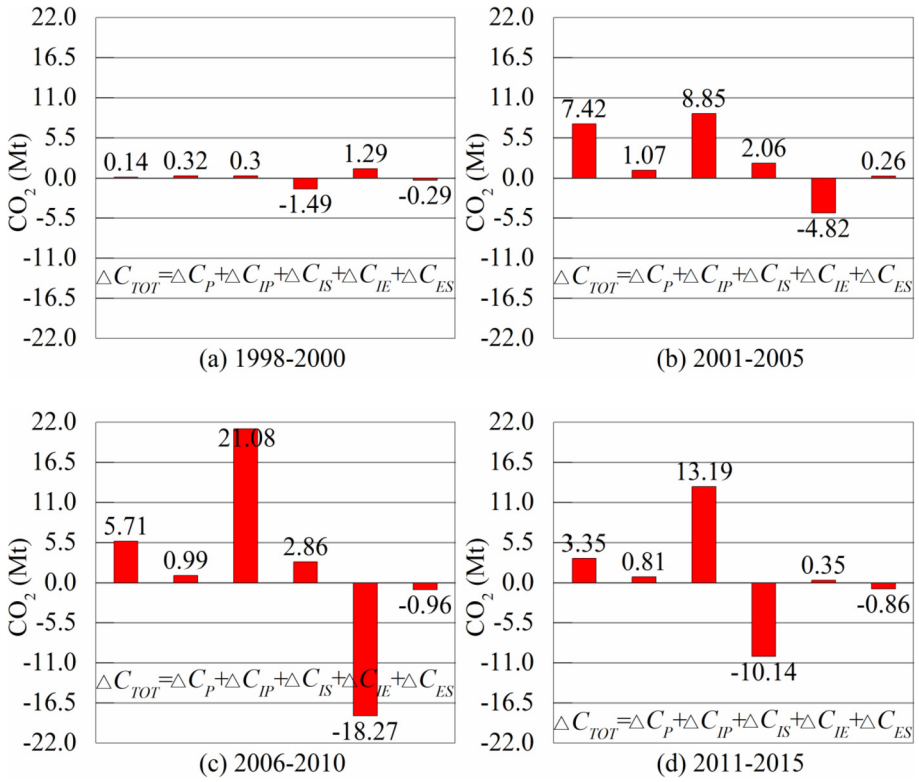

Fig. 3. Additive decomposition results of the CE changes for industrial energy consumption in the four stages (ΔC_{TOT}, ΔC_P, ΔC_{IP}, ΔC_{IS}, ΔC_{IE} and ΔC_{ES} denote the total changes in the total CE and the effects of population, economic output, industrial structure, energy intensity and energy mix, respectively). (a) 1998–2000. (b) 2001–2005. (c) 2006–2010. (d) 2011–2015.

Table 3
Contributions of various drivers to the total CE changes (unit: %).

Periods	Changes	Population	Economic output	Industrial structure	Energy intensity	Energy mix
1998–1999	16.97	2.14	−1.24	−32.67	50.45	−1.72
1999–2000	−13.04	1.79	4.41	0	−16.08	−3.16
2000–2001	23.5	1.91	2.46	10.73	5.16	3.24
2001–2002	9.02	2.03	14.01	−3.03	−1.42	−2.55
2002–2003	12.8	0.51	16.92	16.54	−21.98	0.81
2003–2004	16.67	2.32	25.05	−6.03	−3.58	−1.08
2004–2005	6.85	3.15	23.21	−0.84	−22.66	4
2005–2006	23.9	2.03	27.29	3.35	−9.75	0.98
2006–2007	5.23	1.54	24.89	−14.94	−6.14	−0.12
2007–2008	−12.2	0.65	27.37	25.32	−59.55	−5.99
2008–2009	−13.3	0.48	16.86	−21.98	−6.47	−2.2
2009–2010	37.31	1.13	24.56	−5.25	9.24	7.63
2010–2011	4.98	0.55	10.07	1.07	−6	−0.71
2011–2012	3.49	0.58	15.48	−7.23	−1.19	−4.17
2012–2013	5.17	0.45	12.99	−8.66	2.19	−1.79
2013–2014	0.58	1.49	12.32	−15.33	3.78	−1.68
2014–2015	0.59	0.51	7.78	−14.62	2.42	4.49
1998–2000	1.72	3.96	3.66	−18.18	15.81	−3.52
2001–2005	89.34	12.91	106.57	24.75	−58.01	3.12
2006–2010	36.28	6.31	134	18.17	−116.12	−6.07
2011–2015	15.6	3.77	61.52	−47.31	1.63	−3.99
1998–2015	203.42	38.6	442.06	−71.36	−182.08	−23.8

Note: "-" denotes the positive (favorable) contribution of mitigating the CE.

4.2.2. Population

Similarly, the additive decomposition effect of population on the CE was 0.32 Mt in 1998–2000 (Fig. 3), indicating that population was also a driver of the CE growth during 1998–2000. In 2001–2005, 2006–2010 and 2011–2015, the decomposition effects increased to 1.07 Mt, 0.99 Mt and 0.81 Mt (Fig. 3), respectively. In total, the effect of population made a specific contribution to the total annual rate of CE growth (2.27%) (Table 4), and for each of the four stages, the average annual contribution rates were 1.98%, 2.58%, 1.26% and 0.75%, respectively (Table 4). Thus, overall, the driving effect of population on the total CE was decreasing but was increasing in stage 2.

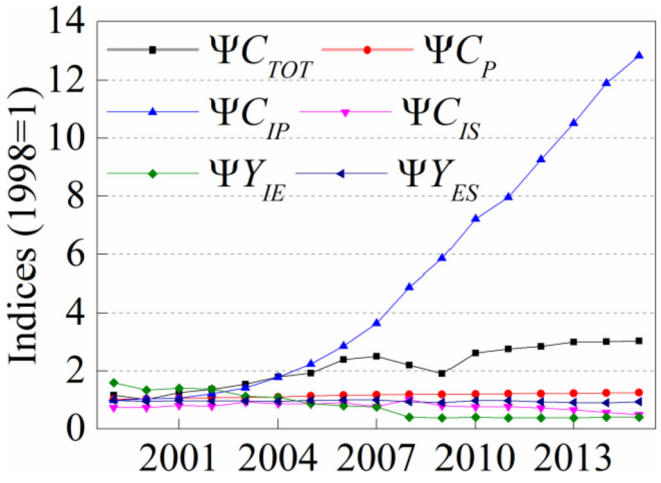

Fig. 4. Trends of cumulative decomposition results of CE changes (ΨC_{TOT}, ΨC_P, ΨC_{IP}, ΨC_{IS}, ΨC_{IE} and ΨC_{ES} denote the total change and the effects of population, economic output, industrial structure, energy intensity and energy mix, respectively).

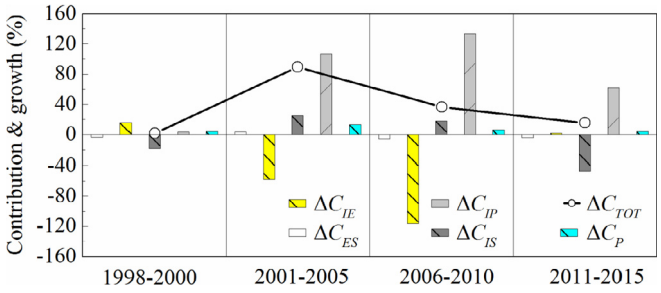

Fig. 5. Change of total CE and the contributions of the decomposed drivers at various stages.

4.2.3. Energy intensity

The average annual mitigation impact of energy intensity on the CE was stronger than those of industrial structure effect and energy mix effect (Table 4). In addition, the effects of the three drivers were all negative and much more sensitive than the two positive effects mentioned above. These results indicated that the reductions in the industrial CE in Nanchang should mainly depend on the utilization and improvement of the three drivers, especially for energy intensity, because the energy intensity effect reflected the overall technological improvement under the guidelines of various environmental laws, regulations, tax policies and other measures proposed by government. In particular, the largest mitigating contribution to the growth rate of CE (11.97%) came from the energy intensity effect (−10.71%); in the four different stages, the average annual contribution rates of energy intensity effect were 7.91%, −11.60%, −23.22% and 0.33%, respectively (Table 4). The corresponding changes in total CE due to energy intensity effect were 1.28 Mt, −4.82 Mt, −18.27 Mt and 0.35 Mt, respectively (Fig. 3). Overall, the energy intensity effect was the most important driver mitigating the CE in Nanchang.

4.2.4. Industrial structure

Industrial structural adjustment could also be considered the important driver lowering the CE in Nanchang; indeed, it had an overall mitigating effect during 1998–2015. For example, the average annual contribution rate of industrial structure to the CE was −4.2% (Table 4), and in the four stages, the corresponding average annual contribution rates were −9.09%, 4.95%, 3.63%, and −9.46%, respectively (Table 4). These results indicated that the adjustment of the industrial structure in Nanchang effectively mitigated the CE on the whole. The effect of industrial structure was positive and had the driving effect in 2001–2005 and 2006–2010 (Fig. 5). These results could also be inferred from the economic output share's change of the high and low discharge groups in Nanchang (Fig. 6).

4.2.5. Energy mix

The energy mix effect had the least impact in lowering the CE in Nanchang during 1998–2015 when compared with the energy intensity and industrial structure, e.g., the average annual contribution rate to the CE was −1.4% (Table 4), and in the four stages, the corresponding contribution rates were −1.76%, 0.62%, −1.21%, and −0.8%, respectively (Table 4). However, the updating and development of energy mix cannot be neglected in the carbon reduction of Nanchang because the prominent mitigation effect of energy mix needed a long time to be realized.

4.3. Drivers of CE's changes from the perspective of different sub-sectors

As mentioned above, there were 32 industrial sub-sectors, so it was essential to decompose the contribution of each sub-sector into the five effects (population, economic output, industrial structure, energy intensity and energy mix). Fig. 7 shows the contributions of the five decomposed effects and their total effect on the total CE during the four different stages for all 32 sub-sectors. The top 5 contributing sub-sectors of the total decomposition effect and corresponding effects of the 5 drivers on the CE during different four stages are shown in Table 5.

During stage 1, the change in the total CE of industrial energy consumption in Nanchang was 14.03×10^4 t (Table 5, Fig. 3). The top 5 contributing sub-sectors were 'smelting and pressing of ferrous metals (I19)', 'production and supply of electric power and heat power (I30)', 'manufacture of raw chemical materials and chemical products (I15)', 'manufacture of paper and paper products (I11)' and 'manufacture of general purpose machinery (I22)', and the total effects from the five drivers were 43.53×10^4 t, -30.48×10^4 t, 12.20×10^4 t, 10.33×10^4 t and

Table 4
Contribution types and trends at various stages and average annual contribution (change) rate.

Effects	Variables	Average annual contribution rate (%)				
		stage 1[a]	stage 2[a]	stage 3[a]	stage 4[a]	whole
/	ΔC_{TOT}	0.86[b]	17.87[b]	7.26[b]	3.12[b]	11.97[b]
Population	ΔC_P	1.98	2.58	1.26	0.75	2.27
Economic output	ΔC_{IP}	1.83	21.31	26.8	12.3	26
Industrial structure	ΔC_{IS}	−9.09	4.95	3.63	−9.46	−4.2
Energy intensity	ΔC_{IE}	7.91	−11.6	−23.22	0.33	−10.71
Energy mix	ΔC_{ES}	−1.76	0.62	−1.21	−0.8	−1.4

Note: [a] Stages 1, 2, 3 and 4 were 1998–2000, 2001–2005, 2006–2010 and 2011–2015, respectively; [b] indicates the average annual change rate of the total CE;/means null; − indicates a negative (mitigation) effect on CE.

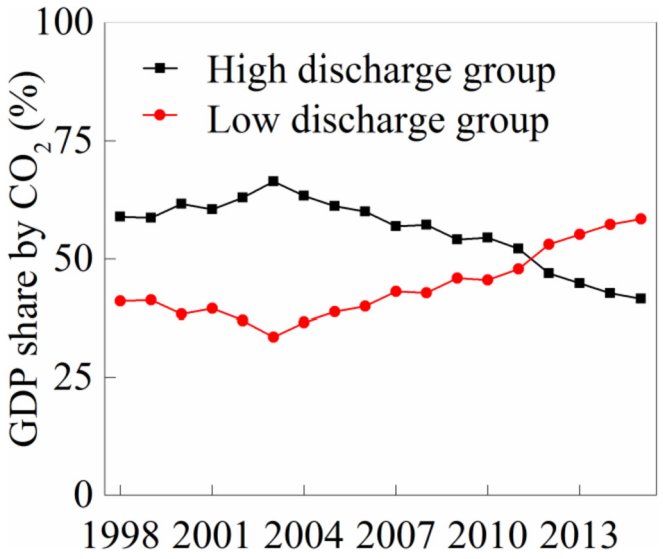

Fig. 6. Change in the share of economic output for the high and low discharge groups in Nanchang (according to the ranking of annual average CE during 1998–2015, the high discharge group corresponded to the top half of sub-sectors, and the low discharge group corresponded to the last half of sub-sectors).

-10.02×10^4 t, respectively. The sum of the effects of the five sub-sectors was 25.57×10^4 t, and the corresponding share of the five sub-sectors in all sectors was 182.28% (Table 5). The effect of the sub-sector I30 was negative (mitigating). This result arose from the changing share of the I30 sub-sector, which was 8.20% in 1998 and decreased greatly to 2.08% in 2000 (Table A7). This decrease also caused an extremely large mitigating effect (-237.10×10^4 t) of industrial structure from sub-sector I30 on the total CE (Table 5, Fig. 7). Similarly, the effect of the sub-sector I22 was negative (mitigating) and mainly arose from changing energy intensity, which was 1.21 t/10^4 CNY in 1998 and decreased greatly to 0.54 t/10^4 CNY in 2000 and caused an extremely large mitigating effect (-8.58×10^4 t) of energy intensity from sub-sector I22 on the total CE. Thus, we could find that this decrease was beneficial in reducing the CE to improve the technological level in the corresponding sub-sector and both decreased the energy intensity and stimulated the corresponding mitigating effect.

During stage 2, the change in the total CE was 742.33×10^4 t (Table 5, Fig. 3). The top 5 contributing sub-sectors were I19, I30, and I15, and 'manufacture of non-metallic mineral products (I18)' and 'manufacture of transport equipment (I24)'. Compared with those in stage 1, the top 3 contributing sub-sectors were invariable, but I18 and I24 replaced I11 and I22, respectively. The reason for this result mainly arose from the rapid development of the two sub-sectors, e.g., the share of sub-sector I18 was 1.88% in 2001 and increased greatly to 3.24% in 2005 (Table A7), which also caused a clear driving effect (28.53×10^4 t) of economic output from sub-sector I18 on the total CE (Table 5, Fig. 7).

During stage 3, the top 5 contributing sub-sectors were I30, I19, I15, I11, and 'smelting and pressing of non-ferrous metals (I20)'. In contrast with stage 1 and 2, the sub-sector I20 was first among the top 5 contributing sectors. The reason for this finding was the quick development of this sub-sector. The share of sub-sector I20 was 3.36% in 2006 and increased to 3.90% in 2010 (Table A7), which also caused a clear driving effect (21.86×10^4 t) of economic output from sub-sector I20 on the total CE (Table 5, Fig. 7). The effect of sub-sector I15 was negative (mitigating), and the reason for this finding is consistent with that for I22.

Clearly different from stages 1, 2 and 3, the top 5 contributing sub-sectors in stage 4 were I19, 'manufacture of communication equipment, computers and other electronic equipment (I26)', 'processing of food from agricultural products (I2)', I18 and I20, and their total effects for the five drivers were 68.54×10^4 t, 61.57×10^4 t, 40.13×10^4 t, 31.76×10^4 t and 24.57×10^4 t, respectively. The sum of the effects of the five sub-sectors was 226.56×10^4 t, and the corresponding share of the five sub-sectors in all sectors was 67.72% (Table 5, Fig. 7). Compared with the former 3 stages, I26 and I2 were first among the top 3 contributing sectors. The reasons for this result were consistent with those for I20.

It should be noted that the energy-intensive sub-sectors I30 and I15 were the third and fifth highest contributing sectors in stage 4, respectively, as a result of the development stagnation or regression of these sub-sectors. For example, the share of sub-sector I30 was 12.06% in 2011 and decreased clearly to 8.83% in 2015 (Table A7). This development stagnation may have arisen from the short-term impact of the economic crisis that began in 2008, which is consistent with the fact that the CEs from fuel combustion were clearly declining and almost stabilized at the level discussed in Section 4.1. In other words, the two energy-intensive sub-sectors might enter again into the top 3 or 5 contributing sectors with the development of more traditional economic patterns and the decline of energy-saving consciousness. Therefore, it could be concluded that it is necessary for us to keep this 'new normal' of economic development (Mi et al., 2017b). Meanwhile, communication and education about energy-saving behaviors should be continuously delivered to strengthen the consciousness of people about a low-carbon style of life.

Overall, the sub-sectors of I19, I30 and I15 should be the top 3 sectors targeted for reducing the CE in Nanchang. However, it could be easily seen that the three sectors were the traditional industries with the characteristics of infrastructure attributes. Namely, it was difficult to inhibit obviously the development of these sectors. Therefore, one potential option based on this result could be to attempt a slow expansion of the economic scale of these sub-sectors or to encourage them to convert gradually to other sub-sectors with a lower CE and high value added. For example, in sub-sector I30, some advanced production process with low CE and high value added should continue to be promoted to reduce or inhibit the use of coal as much as possible. Then, in the 'new normal' of economic development, I26 and I2 were the first among the top 3 sectors and thus should receive the almost same attention as the three mentioned above. The difference was that the two sectors were the new industries partly with the characteristics of high-tech attributes. That is to say, it was necessary to promote (not inhibit) the development of the two sectors for upgrading the industrial structure of Nanchang city. Therefore, energy efficiency should be given enough attention for reducing the CE. For example, in sub-sector I26, we should try hard to improve the related technological level and energy efficiency and eliminate unnecessary waste in this sector. In addition, these sub-sectors I11, I18, I20, I22 and I24 should also be given much attention when designing related mitigation policies because these sub-sectors were often within the top 5 contributing sectors. It could be found that the five sectors were the traditional manufacturing industries. Therefore, based on the characteristics of these sectors, these manufacturing processes with backward production capacity and high-energy consumption could be eliminated as soon as possible. But, the cores of these manufacturing processes which could not be eliminated should be given enough attention for improving the related technological level and energy efficiency.

4.4. Uncertainties and applicability

Like any other methods, the methodology used in this article is

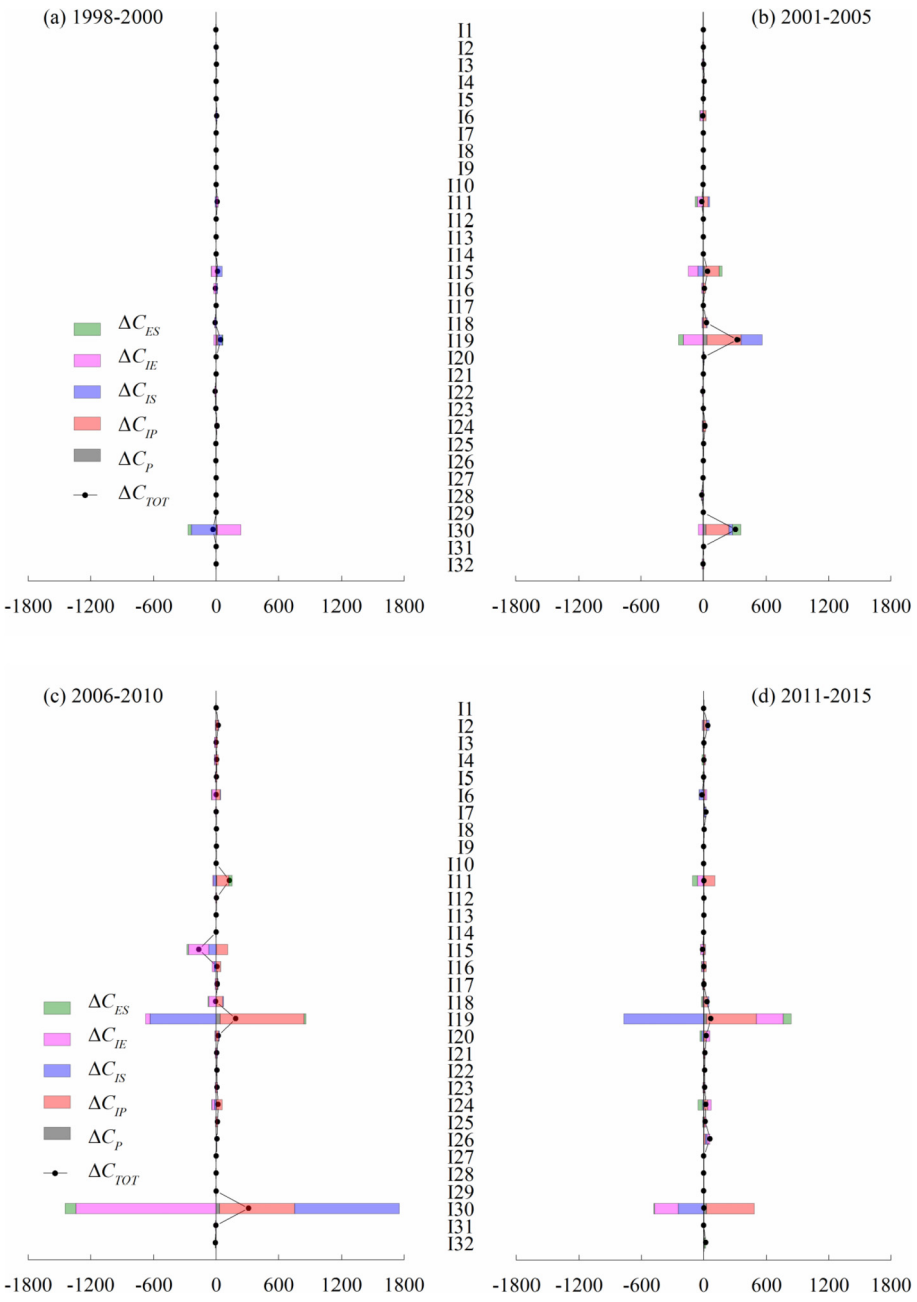

Fig. 7. The contributions of the five effects and total effect on the total CE during four different stages for all sub-sectors (10^4 t). (a) 1998–2000. (b) 2001–2005. (c) 2006–2010. (d) 2011–2015.

also subject to some uncertainties. The main uncertainties may be rooted in the following points. First, the emission factors of different kinds of energy in different industrial sub-sectors may have some inherent uncertainties. For example, we directly adopt the related factors of China in the IEA statistics for calculating the total CE of Nanchang. Second, the calculation model may have some unpredicted and systematic errors, such as the errors of the rounding process. In addition, the lack of some data sources may make the calculated result of Nanchang less than that of the reality. For example, the amount and share of the WAM sub-sector in Nanchang were marginal, and the fossil fuel consumption in this sector was close to 0 in most years; thus, this WAM industry was excluded. This omission may result in the calculated CEs being lower than the reality.

The first calculation and analysis of Nanchang's CE from industrial energy consumption can at least provide us with some new knowledge from the perspective of an underdeveloped city. At the same time, this analysis can give us some reliable strategies or countermeasures for carbon reduction and sustainable development in Nanchang. On the other hand, the methodology of this paper can also be used in the other underdeveloped cities as long as the related basic data on energy consumption can be obtained. These underdeveloped cities can be in any other province or similar countries, especially those near the PLEEZ in Jiangxi Province, China. In the PLEEZ, there are many cities that have similar features as Nanchang, and thus, in future work, we plan to account for the CE of these underdeveloped cities and analyze their potential low-carbon development strategies.

5. Conclusions and policy implications

So far, little attention has been paid to CO_2 reductions in underdeveloped cities for combating climate change, especially in central China. Taking Nanchang as a case study, we first computed

Table 5
The top 5 contributing sub-sectors of the total decomposition effect and corresponding effects of the 5 drivers on the CE during the four different stages (10^4 t).

Stages	Sub-sectors et al.	Total effect	Population	Economic output	Industrial structure	Energy intensity	Energy mix
1	I19	43.53	9.82	9.08	41.72	−22.73	5.64
	I30	−30.48	6.81	6.29	−237.10	226.95	−33.42
	I15	12.20	5.98	5.53	48.63	−44.14	−3.79
	I11	10.33	2.25	2.08	−9.73	15.00	0.74
	I22	−10.02	0.42	0.39	−1.21	−8.58	−1.04
	Sum of five	25.57	25.28	23.37	−157.69	166.49	−31.87
	All sectors	14.03	32.31	29.87	−148.53	129.16	−28.78
	Share of five	182.28%	78.24%	78.24%	106.17%	128.90%	110.76%
2	I19	326.64	38.88	320.81	203.73	−189.29	−47.49
	I30	311.95	26.89	221.91	34.73	−45.34	73.76
	I15	40.71	16.68	137.67	−48.46	−94.87	29.68
	I18	31.17	3.46	28.53	9.13	−9.12	−0.84
	I24	17.57	2.80	23.13	−2.88	−3.99	−1.49
	Sum of five	728.04	88.71	732.06	196.26	−342.61	53.62
	All sectors	742.33	107.30	885.47	205.62	−482.00	25.94
	Share of five	98.07%	82.67%	82.67%	95.45%	71.08%	206.69%
3	I30	312.37	33.97	721.92	1001.61	−1341.75	−103.37
	I19	186.34	38.09	809.48	−635.19	−43.26	17.22
	I15	−166.73	5.06	107.44	−69.99	−195.04	−14.20
	I11	126.10	5.51	117.11	−23.43	−7.32	34.23
	I20	21.30	1.03	21.86	9.91	−9.83	−1.67
	Sum of five	479.38	83.66	1777.81	282.91	−1597.20	−67.80
	All sectors	570.73	99.20	2108.08	285.83	−1826.85	−95.52
	Share of five	83.99%	84.33%	84.33%	98.98%	87.43%	70.98%
4	I19	68.54	29.02	473.68	−769.64	259.53	75.94
	I26	61.57	1.01	16.56	16.63	27.39	−0.03
	I2	40.13	1.63	26.58	25.31	−11.33	−2.06
	I18	31.76	2.28	37.18	12.37	−8.44	−11.63
	I20	24.57	1.50	24.49	−17.19	34.41	−18.63
	Sum of five	226.56	35.44	578.50	−732.53	301.56	43.59
	All sectors	334.54	80.80	1318.85	−1014.34	34.84	−85.62
	Share of five	67.72%	43.86%	43.86%	72.22%	865.46%	−50.90%

Note: the sub-sectors were sorted by their corresponding absolute value of the size.

this city's CE from industrial energy consumption and then analyzed the corresponding drivers by using the LMDI method. Some results were acquired as follows.

The total CE of industrial energy consumption increased from 8.17 Mt in 1998 to 24.79 Mt in 2015 with an annual average increase amount of 0.98 Mt and a growth rate of 6.75%. Nevertheless, this CE had a clearly variable change during 2006–2010 because of the global economic crisis in 2008.

The contributions of the population effect, economic output effect, industrial structural effect, energy intensity effect and energy mix effect were 3.15 Mt, 36.11 Mt, −5.83 Mt, −14.87 Mt and −1.94 Mt, respectively. These results indicated that the growth in economic output was the most prominent driver of CE growth followed by population growth. The average annual contribution rates were 26.00% for economic output and 2.27% for population. However, energy intensity exhibited the most clear mitigation effects followed by industrial structure, and the energy mix effect played a minor role in reducing CE. The corresponding average annual contribution rates were −10.71% for energy intensity, −4.20% for industrial structure and −1.40% for energy mix.

The CE for “fuel combustion” had clear variability during the economic crisis, but the CE from “electricity and heat” had only a slight fluctuation. The reasons were that people could directly reduce all kinds of expenditures in everyday life when the crisis arrived, which could reduce fuel usage and the corresponding CEs. However, the use of electricity and heat could not fall because these consumption behaviors were dominated mainly by people's habits and customs.

In the traditional pattern of economic development, I19, I30 and I15 were always among the top 3 contributing sectors of the CE. However, in the ‘new normal,’ I26 and I2 were first among the top 3 contributing sectors. In addition, I11, I18, I20, I22 and I24 were often among the top 5 sectors.

Based on these results, we recommend some particular countermeasures and suggestions for reducing Nanchang's CE.

First, it is important and necessary to expand the communication and education about the low-carbon lifestyle. At the same time, it is necessary to design related policies and legal norms to help people develop good habits and energy-saving customs to enjoy a low-carbon lifestyle.

Then, the local government in Nanchang city should seek a trade-off between economic development and carbon reduction. The related carbon reduction policies should gradually counteract the economic output effect by activating energy intensity and industrial structure effects. For example, a circular economy should be promoted so that the total consumption of raw materials and fossil fuels and the corresponding CE can be minimized.

Next, people should pay more attention to improving the level of technology in all sub-sectors of industries. For example, some regulatory policy instruments (i.e., carbon reduction liability and emission rights trading) should be more aggressively implemented to encourage industrial enterprises to improve their energy use efficiency and lower the corresponding intensity.

Fourth, adjusting the industrial structure should also be the focus of carbon reduction policy, especially in the sub-sectors I2, I11, I15, I18, I19, I20, I22, I24, I26 and I30. For the traditional industries with the characteristics of infrastructure attributes, a slower expansion of the economic scale of these sub-sectors should be encouraged to reduce the corresponding CE. For the new industries partly with the characteristics of high-tech attributes, the related technological level and energy efficiency should be improved and unnecessary waste should be eliminated. For the traditional manufacturing industries, these manufacturing

processes, with backward production capacity and high-energy consumption, could be eliminated. However, the cores of manufacturing processes which could not be eliminated should be given enough attention for improving the related technological level and energy efficiency.

Last, the government should devote itself to the construction of a diverse, safe, clean, and efficient energy supply system. Specifically, clean and renewable energy and related innovative technologies should be supported for further development, such as high-efficiency and low-cost photovoltaic battery technology, solar thermal power generation technology, and ground source heat pumps.

Author contributions

Junsong Jia, Jiehong Chen and Chundi Chen designed research; Zhihai Gong, Dongming Xie and Jiehong Chen performed research and analyzed the data; Junsong Jia and Zhihai Gong wrote it. All authors read and approved the final manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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Appendix A

Table A1
Classification of industrial sub-sectors studied in this paper.

No.	Sub-sectors
I1	Mining and Processing of Nonmetal Ores
I2	Processing of Food from Agricultural Products
I3	Manufacture of Foods
I4	Manufacture of Beverages
I5	Manufacture of Tobacco
I6	Manufacture of Textile
I7	Manufacture of Textile Wearing Apparel, Footware and Caps
I8	Manufacture of Leather, Fur, Feather and Related Products Processing of Timber
I9	Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products
I10	Manufacture of Furniture
I11	Manufacture of Paper and Paper Products
I12	Printing, Reproduction of Recording Media
I13	Manufacture of Articles For Culture, Education and Sport
I14	Processing of Petroleum, Coking, Processing of Nuclear Fuel
I15	Manufacture of Raw Chemical Materials and Chemical Products
I16	Manufacture of Medicines
I17	Manufacture of Rubber & Plastics
I18	Manufacture of Non-metallic Mineral Products
I19	Smelting and Pressing of Ferrous Metals
I20	Smelting and Pressing of Non-ferrous Metals
I21	Manufacture of Metal Products
I22	Manufacture of General Purpose Machinery
I23	Manufacture of Special Purpose Machinery
I24	Manufacture of Transport Equipment
I25	Manufacture of Electrical Machinery and Equipment
I26	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
I27	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work
I28	Manufacture of Artwork and Other Manufacturing
I29	Processing of waste material recycling and resources waste
I30	Production and Supply of Electric Power and Heat Power
I31	Production and Supply of Gas
I32	Production and Supply of Water

Table A2
CE coefficients of different type's energy

Energy type	Carbon content (kg/GJ)[a]	Carbon oxidation (%)[a]	Emission rate (kg-CO_2/TJ)[a]	Net calorific value (TJ/Gg)[a]	Emission Coefficient (t-CO_2/t)
Crude coal	25.8	100	94600	20.9	1.977
Washed coal	25.8	100	94600	26.3	2.488
Other washed coal	25.8	100	94600	8.4	0.795
Briquette	26.6	100	97533	17.6	1.717
Coke	29.2	100	107067	28.2	3.019
Coke oven gas	12.1	100	44367	16726[b]	7.421[c]
Natural gas	15.3	100	56100	38931[b]	21.840[c]
Liquefied natural gas	17.5	100	64167	44.2	2.836
Crude oil	20.0	100	73333	42.3	3.102
Gasoline	20.2	100	74067	43	3.185
Kerosene	19.5	100	71500	44.1	3.153
Diesel	20.2	100	74067	43	3.185
Fuel oil	21.1	100	77367	40.4	3.126
Liquefied Petroleum Gas	17.2	100	63067	47.3	2.983
Other petroleum products	20.0	100	73333	40.2	2.948

Note: [a] The value was the IPCC recommended value; [b] The unit was KJ/m^3; [c] The unit was t- $CO_2/10^4$ m^3.

Table A3
CE coefficient of electricity (t-CO_2 /10^4kwh)

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006
Coefficient	8.922	8.886	8.850	8.835	8.820	8.805	8.790	8.670	8.620
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Coefficient	8.220	7.970	7.900	7.580	7.640	7.700	7.760	7.820	7.768

Table A4
Detailed additive decomposition results of total CE and five drivers (Mt)

Periods	Changes	Population	Economic output	Industrial structure	Energy intensity	Energy mix
1998–1999	138.62	17.48	−10.13	−266.86	412.15	−14.02
1999–2000	−124.59	17.07	42.18	0	−153.66	−30.18
2000–2001	195.26	15.88	20.44	89.17	42.84	26.93
2001–2002	92.59	20.8	143.71	−31.12	−14.6	−26.21
2002–2003	143.22	5.65	189.32	185.08	−245.88	9.05
2003–2004	210.4	29.24	316.09	−76.09	−45.22	−13.62
2004–2005	100.87	46.44	341.75	−12.44	−333.7	58.83
2005–2006	375.97	31.93	429.28	52.71	−153.38	15.43
2006–2007	101.91	30.11	485.06	−291.25	−119.74	−2.28
2007–2008	−250.2	13.3	561.31	519.44	−1221.48	−122.77
2008–2009	−239.49	8.73	303.64	−395.85	−116.46	−39.56
2009–2010	582.54	17.67	383.47	−82.03	144.26	119.18
2010–2011	106.78	11.77	215.99	22.92	−128.64	−15.25
2011–2012	78.45	13.12	348.42	−162.65	−26.7	−93.74
2012–2013	120.47	10.37	302.52	−201.76	51	−41.66
2013–2014	14.29	36.53	301.71	−375.49	92.67	−41.13
2014–2015	14.55	12.61	191.81	−360.19	59.68	−28.78
1998–2000	14.03	32.31	29.87	−148.53	129.16	25.94
2001–2005	742.33	107.3	885.47	205.62	−482	−95.52
2006–2010	570.73	99.2	2108.08	285.83	−1826.85	−85.62
2011–2015	334.54	80.8	1318.85	−1014.34	34.84	−14.02
1998–2015	1661.63	315.27	3610.94	−582.88	−1487.29	−30.18

Table A5
Detailed multiplicative decomposition results of total CE and five drivers

Periods	Changes	Population	Economic output	Industrial structure	Energy intensity	Energy mix
1998–1999	1.17	1.02	0.99	0.74	1.59	0.98
1999–2000	0.87	1.02	1.05	1	0.84	0.97
2000–2001	1.23	1.02	1.02	1.1	1.05	1.03
2001–2002	1.09	1.02	1.14	0.97	0.99	0.98
2002–2003	1.13	1	1.17	1.17	0.81	1.01
2003–2004	1.17	1.02	1.26	0.95	0.97	0.99
2004–2005	1.07	1.03	1.25	0.99	0.8	1.04
2005–2006	1.24	1.02	1.28	1.03	0.92	1.01
2006–2007	1.05	1.02	1.27	0.86	0.94	1
2007–2008	0.88	1.01	1.34	1.31	0.53	0.94
2008–2009	0.87	1.01	1.2	0.79	0.93	0.98
2009–2010	1.37	1.01	1.23	0.96	1.08	1.07
2010–2011	1.05	1.01	1.1	1.01	0.94	0.99
2011–2012	1.03	1.01	1.16	0.93	0.99	0.96
2012–2013	1.05	1	1.14	0.92	1.02	0.98
2013–2014	1.01	1.02	1.13	0.86	1.04	0.98
2014–2015	1.01	1.01	1.08	0.86	1.02	1.05
1998–2000	1.02	1.04	1.04	0.84	1.17	0.97
2001–2005	1.89	1.1	2.14	1.19	0.66	1.02
2006–2010	1.36	1.06	3.14	1.17	0.37	0.95
2011–2015	1.16	1.04	1.77	0.64	1.02	0.96
1998–2015	3.03	1.23	11.16	0.68	0.37	0.88

Table A6
Cumulatively multiplicative results of total CE's changes and five drivers

Years	Changes	Population	Economic output	Industrial structure	Energy intensity	Energy mix
1999	1.17	1.02	0.99	0.74	1.59	0.98
2000	1.02	1.04	1.04	0.74	1.34	0.95
2001	1.26	1.06	1.06	0.81	1.41	0.98
2002	1.37	1.08	1.21	0.79	1.39	0.96
2003	1.54	1.08	1.42	0.92	1.13	0.96
2004	1.80	1.11	1.79	0.87	1.09	0.95
2005	1.93	1.14	2.24	0.87	0.88	0.99
2006	2.39	1.16	2.86	0.89	0.80	1.00
2007	2.51	1.18	3.65	0.77	0.76	1.00
2008	2.20	1.19	4.89	1.01	0.40	0.94
2009	1.91	1.19	5.86	0.80	0.37	0.92
2010	2.62	1.21	7.21	0.76	0.40	0.98
2011	2.76	1.21	7.96	0.77	0.38	0.97
2012	2.85	1.22	9.27	0.72	0.38	0.93
2013	3.00	1.22	10.52	0.66	0.38	0.91
2014	3.02	1.24	11.89	0.57	0.40	0.90
2015	3.03	1.25	12.85	0.49	0.41	0.94

Table A7
Shares of different sub-sectors in total industrial GDP during 1998–2015

Share	1998	1999	2000	2001	2002	2003	2004	2005	2006
I1	0.62	0.58	0.39	0.11	0.11	0.00	0.17	0.07	0.14
I2	9.47	7.11	5.98	6.22	5.18	4.01	5.48	5.31	6.29
I3	1.57	1.70	1.92	2.30	2.36	2.81	2.85	2.48	2.42
I4	1.49	1.52	1.40	1.25	1.28	1.28	1.32	1.32	1.40
I5	3.52	4.62	4.38	6.26	7.68	7.54	5.54	5.04	4.52
I6	4.52	4.90	5.39	5.56	4.74	5.29	5.21	5.40	5.40
I7	1.63	1.73	1.85	2.17	1.86	0.85	1.76	2.00	1.98
I8	0.75	0.62	0.46	0.18	0.23	0.14	0.25	0.22	0.32
I9	0.38	0.24	0.31	0.36	0.22	0.12	0.32	0.38	0.44
I10	0.32	0.31	0.25	0.11	0.10	0.02	0.03	0.08	0.16
I11	1.97	2.17	1.66	1.61	1.00	0.66	0.72	2.13	2.91
I12	3.35	3.70	3.61	3.63	3.03	2.73	2.63	2.36	2.02
I13	1.06	1.21	1.06	0.90	0.84	0.47	0.39	0.38	0.51
I14	0.06	0.04	0.02	0.27	0.31	0.29	0.11	0.25	0.28
I15	5.39	6.58	7.42	8.37	7.30	5.44	5.43	5.65	4.46
I16	6.11	8.41	9.96	9.31	9.44	13.47	11.02	10.18	9.27
I17	2.22	2.76	2.41	2.45	2.13	1.57	1.73	1.87	2.04
I18	3.37	3.08	2.53	1.88	1.79	1.76	2.76	3.24	4.15
I19	5.90	6.03	6.98	8.89	10.38	12.43	10.47	11.41	12.54
I20	1.10	1.33	1.43	1.12	0.76	1.12	1.57	2.29	3.36
I21	1.93	1.63	1.36	1.14	1.14	0.66	1.28	1.71	2.45
I22	4.24	3.96	3.79	0.19	3.46	2.61	3.09	1.66	1.71
I23	4.08	3.75	2.26	1.62	1.98	0.75	1.51	1.59	1.79
I24	18.05	19.75	20.67	21.42	22.04	21.70	21.60	18.76	16.91
I25	4.32	4.34	4.57	4.15	3.91	4.10	6.00	6.61	6.10
I26	2.45	3.11	3.76	4.46	3.04	4.11	2.80	3.83	2.98
I27	0.19	0.31	0.19	0.11	0.19	0.18	0.19	0.17	0.12
I28	1.19	1.39	1.22	0.92	0.81	0.12	0.18	0.44	0.36
I29	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.11	0.19
I30	8.20	2.43	2.08	2.32	2.03	2.94	2.87	2.35	2.31
I31	0.00	0.12	0.10	0.00	0.00	0.00	0.00	0.05	0.05
I32	0.56	0.58	0.59	0.73	0.67	0.84	0.71	0.66	0.44
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Share	2007	2008	2009	2010	2011	2012	2013	2014	2015
I1	0.06	0.14	0.17	0.17	0.11	0.13	0.12	0.11	0.13
I2	6.06	6.36	7.28	8.10	9.64	12.17	12.96	13.55	14.06
I3	2.36	2.19	2.34	2.25	1.89	2.13	2.30	2.30	2.38
I4	1.43	1.60	1.42	1.31	1.46	1.45	1.43	1.36	1.29
I5	5.40	3.31	3.94	3.37	3.28	3.26	3.26	3.42	3.00
I6	7.05	6.35	6.66	6.72	5.13	1.20	0.99	1.05	1.06
I7	1.08	1.63	1.78	1.43	1.21	5.37	5.77	5.97	5.97
I8	0.30	0.43	0.57	0.51	0.50	0.73	0.74	0.80	0.88
I9	0.63	0.55	0.74	0.84	0.88	1.01	1.01	0.77	0.72
I10	0.11	0.13	0.18	0.23	0.17	0.20	0.21	0.22	0.19
I11	2.58	2.32	1.88	1.68	1.61	1.83	1.66	1.57	1.64
I12	2.29	2.21	2.34	2.17	1.81	1.91	2.02	2.18	1.93
I13	0.58	0.61	0.62	0.68	0.68	1.11	0.93	0.94	1.00
I14	0.35	0.22	0.19	0.15	0.19	0.29	0.16	0.00	0.00
I15	4.51	2.88	2.45	2.62	2.95	3.69	3.32	2.86	2.80
I16	7.84	7.29	7.22	6.43	6.12	6.10	5.80	5.72	6.16
I17	2.40	2.71	2.61	2.40	2.18	1.89	1.91	2.02	2.17
I18	4.14	3.86	3.87	3.76	3.79	3.89	4.22	4.61	4.56
I19	10.72	7.76	4.99	4.53	4.71	4.19	3.53	2.54	1.77
I20	4.16	4.61	3.84	3.90	4.05	3.56	3.21	2.90	2.60
I21	2.54	2.77	2.85	3.00	3.00	3.17	3.40	3.55	3.70
I22	1.95	1.85	2.14	2.35	2.68	2.80	2.82	2.49	2.46
I23	1.88	2.27	2.52	2.60	2.93	3.22	3.24	3.22	3.20
I24	15.98	12.36	12.82	14.02	12.70	12.05	11.87	12.28	12.26
I25	7.60	7.07	7.07	7.33	7.99	6.11	6.11	5.99	5.96
I26	3.11	3.31	4.74	4.42	5.16	4.61	5.65	6.76	7.91
I27	0.13	0.11	0.10	0.11	0.08	0.14	0.14	0.15	0.16
I28	0.41	0.22	0.24	0.30	0.41	0.10	0.00	0.00	0.00
I29	0.18	0.25	0.18	0.17	0.08	0.11	0.11	0.11	0.13
I30	1.74	12.28	11.81	12.04	12.06	11.07	10.59	9.55	8.83
I31	0.07	0.07	0.08	0.07	0.09	0.07	0.07	0.53	0.57
I32	0.36	0.26	0.37	0.32	0.44	0.45	0.45	0.48	0.49
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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